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5                   PERMANENT MAGNET MOTOR ASSEMBLY HAVING A DEVICE AND  
                    METHOD OF REDUCING PARASITIC LOSSES

FIELD OF INVENTION

                  The present invention relates generally to permanent magnet motor  
10   assemblies, and more particularly to devices and methods for improving motor  
efficiency by reducing parasitic losses.

BACKGROUND OF THE INVENTION

                  The ability of flywheels to accept and release energy over relatively short  
15   time periods has been known for many years and energy storage flywheels have  
been used, or proposed for use, in a variety of applications. Such proposed  
and actual use applications include motor vehicle applications and stand alone  
supplemental energy sources.

20               Flywheels store energy by spinning a rotor about an axis, the rotor  
having magnets attached thereto for generating a magnetic field (in the form of  
magnetic flux lines), which reacts with a motor stator to produce torque. The  
motor stator is in the form of a plate with a cut-out section for receiving a  
copper coil. During acceleration of the rotor, energy is transferred by the motor  
25   to the rotor and can be stored in the rotor. However, some of the energy is not  
transferred to the rotor, but is instead lost in the motor stator, resulting in

undesirable heat generation in the stator and reducing the efficiency of the motor. Losses in the motor stator, e.g. losses resulting from eddy currents, are referred to as "parasitic" losses. Therefore, it would be desirable to provide an improved flywheel having a mechanism to reduce or substantially eliminate  
5 such parasitic losses between the magnet and the stator.

#### SUMMARY OF THE INVENTION

A permanent magnet motor assembly is disclosed including a device and method for shielding a stator of the motor against stray magnetic fields which  
10 produce parasitic losses. The motor assembly includes the stator, a rotor, and a shield, wherein the stator has a cut-out section or groove for receiving a coil. The coil is preferably made of strands of copper having a specified number of turns. A rotor positioned adjacent the coil rotates about an axis, as a result of interaction between current in the coil and the magnetic field generated by  
15 magnets mounted on the rotor.

Each of the magnets preferably is mounted along a length of the rotor and includes a proximal end positioned near the stator and another end opposite the proximal end. The shield covers the proximal end of each magnet  
20 to reduce magnetic flux leakage through the proximal end of the magnet. Magnetic flux leakage occurs when portions of the magnetic field, instead of reaching the rotor, either interfere with the stator or escape the system. Such leakage results in parasitic losses in the motor assembly. Specifically, these

stray magnetic field lines can produce eddy current losses in the stator, generating heat and further reducing system efficiency. By providing a shield covering the proximal end of each magnet, such stray magnetic field lines are re-directed away from the stator, thereby improving system efficiency.

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Preferably, in the herein described invention, the rotor is made of magnetic steel and the shield is also made of magnetic steel. In one illustrative embodiment, the shield is a magnetic steel cup extending around the proximal end of the magnet which can be designed to fit tightly against the rotor, such that the magnetic steel cup is substantially integral with the rotor. In another illustrative embodiment, the shield is a snap-fit ring of magnetic steel extending around the rotor and fitting within a cut-out portion of the rotor.

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Other aspects and embodiments of the invention are discussed below.

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#### BRIEF DESCRIPTION OF THE DRAWING

For a fuller understanding of the nature and desired objects of the present invention, reference is made to the following detailed description taken in conjunction with the accompanying drawing figures wherein like reference characters denote corresponding parts throughout the several views and wherein:

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FIG. 1 is a partial cross-sectional side view through a permanent magnet motor assembly according to the present invention;

FIG. 2 is a plan view of the motor assembly of FIG. 1 showing the relative positions of the rotor, magnets, and stator;

FIG. 3 is a perspective view of a section of copper coil which can be arranged in the stator assembly;

5        FIG. 4 is a partial cross-sectional side view of one arrangement of the motor shield including a magnetic steel cup according to the present invention;

FIG. 5A is a partial cross-sectional side view of another arrangement of the motor shield including a snap-fit steel ring according to the present invention; and

10        FIG. 5B is a plan view of the steel ring of FIG. 5A.

#### DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

Referring now to the various figures of the drawing wherein like reference characters refer to like parts, there is shown in the various views of  
15        FIGS. 1 and 2 a motor assembly including a rotor 10 which produces torque as it rotates about an axis 11. A stator 12 includes a plate 14 having a cut-out section or groove 16 for receiving a coil 18. The coil 18 includes a top and a bottom and is suspended within the groove 16 at its top thereof (as shown in  
20        FIG. 1). The bottom of the coil 18 is positioned within a hollow area 19 formed by the rotor that is configured in the shape of a "U". The particular design of the rotor provides that during rotation the rotor 10 does not contact the coil 18, which remains stationary. The rotor includes a top and bottom ends arranged in a longitudinal direction parallel to the coil 18. The top end of the rotor is

proximate the stator. At the bottom of the rotor, the rotor has a thickness  $e$  in the longitudinal direction, where the bottom of the coil is positioned a distance  $d+e$  from the bottom of the rotor 10.

5           One or more magnets 20 are mounted along a length  $l$  of the rotor, preferably located radially between the coil 18 and the rotor 10. As shown in FIG. 1, according to a preferred design of the motor assembly, the rotor 10 includes a first rotor section 10a and a second rotor section 10b, with the hollow area 19 being defined as the region between the first and second rotor sections. In the embodiment of FIG. 1, magnet 20 is mounted lengthwise on the second rotor section 10b and includes a proximal end positioned at a height corresponding to the distance  $a+b$  below the stator 12, extending from approximately the top of the first rotor section 10a downward into the hollow area 19. The bottom of the magnet 20 is preferably positioned at a distance  $c$  from the bottom of the coil 18, although in other embodiments the magnet and coil can terminate at approximately the same point. The magnet 20 acts as a field source for driving the rotor 10, which in conjunction with current in the coil 18, causes rotation of the rotor 10 about the axis 11. Useful work is performed along the length of the magnet 20 in a manner well known in the art.

As shown in FIG. 2, the one or more magnets 20 are positioned radially between the first rotor section 10a and the second rotor section 10b and are

preferably attached to the second rotor section 10b. In the present embodiment four magnets 20 are shown, but the number of magnets is not limited to four, and in other embodiments more or fewer magnets can be used.

In a preferred arrangement, the magnets 20 are each mounted on the rotor, adjacent magnets having opposite polarities, thereby producing alternating magnetic field, or flux lines 22. The magnetic field lines produced by the magnets 20 provide energy for driving the rotor, causing the rotor to rotate about its axis. The magnets can be made of a number of materials known in the art, including those embodying rare earth elements, for example: neodymium boron iron (NdBFe), samarium cobalt (SmCo), and aluminum nickel cobalt (AlNiCo).

As shown in FIG. 1, a shield 30 is attached to the rotor 10 and is preferably arranged above the magnet 20 to cover the top end of the magnet. The shield can be made of magnetic steel, for example, a material similar in composition to the rotor, or other materials as herein described. The magnetic field lines 22 produced by the magnet 20, as shown in FIG. 2, generally are directed radially toward the rotor 10 and the coil 18. However, at the ends of the magnet 20, the magnetic field lines tend to curve away from the magnet 20. In prior art motors, in which there is no shield or cap covering an end of the magnet adjacent the stator, these field lines either interfere with the stator or escape from the rotor, thereby lowering system efficiency. The shield 30 as shown in FIG. 1 substantially eliminates flux leakage from the proximal end of

the magnet 20 and redirects the field lines toward the rotor 10.

FIG. 3 illustrates a 120° section of coil 24 preferably used in the stator of the motor assembly along with two similar sections to form the coil 18. The coil depicted in FIG. 3 is one section of a three-phase motor, but a similar coil can be used with a motor having two or more phases, as is known in the art. As used in the flywheel system of FIG. 1, the three sections 24 are attached together to form a 360° section of coil fixed in the stator 12. The coil section 24 can be positioned within the hollow area 19 of the rotor 10, as shown in FIG. 1.

The coil section 24 preferably is made of copper and includes a specified number of turns. As shown in FIG. 3, the coil section can be made of 16-gauge copper wire wrapped in 29 turns. The wire preferably is broken into parallel strands which are twisted together in order to minimize eddy current losses, according to a method known in the art. The coil 18 (including multiple sections 24) is arranged within the hollow area 19 as shown in FIGS. 1 and 2. Useful work is produced in a central region 26 of the coil section 24 which is arranged radially across from the magnet.

The stator 12, as depicted in FIG. 1, includes the plate 14 which is preferably made of aluminum or another thermally conductive material. To hold the coil 18, an epoxy or other thermally conductive substance is used, which, along with the plate 14, functions to remove heat from the coil 18

during rotation of the rotor 10. The shield 30 tends to block stray flux lines from impacting the stator and causing further heat build-up on the stator. By providing a shield, additional heat and eddy current losses are substantially eliminated from the stator 12. The total heat measured on the stator, which  
5 can amount to hundreds of watts of energy in prior art motors, is reduced by about one to two orders of magnitude using the shield 30 as taught by the present invention.

FIG. 4 illustrates one embodiment of the shield 30 according to the  
10 present invention, in which the shield comprises a cup 40 which rests tightly against the rotor 10 on one side and against each magnet 20 on another side, covering the top end of the magnet 20. The cup preferably is made of magnetic steel or a similar material, such as the material used in the rotor 10. Materials  
15 useful for constructing the cup 40 include carbon steels such as 1018 and 1026, and high strength alloys such as 4340 steel. As shown in FIG. 4, the cup 40 includes a shielding portion 42 covering the top end of the magnet. Preferably, the shielding portion 42 includes a taper at the top end thereof to direct any stray magnetic flux lines toward the rotor 10. In a preferred method of manufacturing the shield, the cup 40 and magnet 20 are first bonded  
20 together and thereafter attached to the rotor 10 as a single piece.

FIGS. 5A and 5B illustrate another embodiment of the shield 30 according to the present invention, in which the shield comprises a ring 50



attached to the rotor and covering each magnet 20. Preferably the ring 50 is a snap-fit ring made of spring steel or a similar material. The ring can include a taper on a shielding portion 52 which covers the top end of the magnet.

5           The rotor 10 preferably is made of a high strength steel material, in order to withstand rotation speeds which can exceed about 25,000 rpm. The herein described components of the motor assembly operate in close proximity to each other. For example, the radial clearance between the coil 18 and the magnet 20 can be approximately 0.025 inches. In an illustrative, exemplary  
10   embodiment described with reference to FIG. 1, the following distances can be used:  $a$  is approximately 0.125 inches,  $b$  is approximately 0.160 inches,  $l$  is approximately 1.60 inches,  $c$  is approximately 0.180 inches,  $d$  is approximately 0.190 inches,  $e$  is approximately 0.150 inches, and  $R$  is approximately 3.00 inches. The above dimensions are not meant to limit the herein described  
15   invention, and are provided for illustrative purposes only.

          Although a preferred embodiment of the invention has been described using specific terms, such description is for illustrative purposes only, and it is to be understood that changes and variations may be made without departing  
20   from the spirit or scope of the following claims.